P515430.PDF [Page: 3 of 6]

DCIEM SL 2000-033

EXPLORING WORK DOMAIN ANALYSIS TECHNIQUES

Philip S. E. Farrell[1] and Ghee Ho[2]
[1]Defence and Civil Institute of Environmental Medicine, Toronto, Canada
[2]University of Hong Kong, Hong Kong

A work domain description is an initial requirement for a Human Factors analysis. Traditional Task Analyses use scenarios generated by Subject Matter Experts (SMEs) to describe the work domain. Cognitive Work Analysis describes the work domain structure using an Abstraction Decomposition Space. Personal Construct Psychology provides the basis for a new method of work domain analysis, which relies on the SME's mental constructs of the domain. Perceptual Control Theory incorporates the work domain functions and variables in its human-machine interaction framework. A study was conducted that developed four work domain descriptions of communication within the Griffon Helicopter using these techniques. The descriptions were compared and unique descriptors were found from each method. It was concluded that a synthesis of techniques promise to provide a comprehensive work domain description towards effective interface design.

INTRODUCTION

A Human Factors analysis begins with generating a work domain description. The description sets the stage for the analysis and puts the design in its proper context. A work domain has been described in terms of structure and variables, affordances and information flow - what it is and what it does.

Gibson defines the work domain as the environment or surroundings that constrains and shapes an organism's perceptions and behaviors (Gibson, 1979). In contrast, Powers portrays the environment as a complex function that transforms input variables into output variables (Powers, Clark, and McFarland, 1960). In many respects, these two perspectives reflect the ecology-based and behavior-based approaches to psychology. Vygotsky in 1928 stated that human activity is mitigated by the environment (Van der Veer and Valsiner, 1994). Watson in 1930 focused on the information flow to and from the environment, which had always been an important part of behaviorism (Weiten, 1989). It seems that both work domain structure and variables are required for a comprehensive description.

More recently, Miller and Vicente (1998) compared task- and ecology-based analyses and concluded that the unification of the approaches is required to obtain the complete set of knowledge needed for good interface design. We concur with this idea, and want to explore the extent to which work domain analysis techniques contribute to a complete work domain description.

A mission scenario is generated as part of a Traditional Task Analysis (TTA). The scenario is not often referred to as a work domain description, however it does have the same role. The scenario is a narrative that describes a mission's conditions and events. Subject Matter Experts (SMEs) generate, review, edit the scenario, and identify the task hierarchy that occurs within the domain.

Cognitive Work Analysis (CWA; Vincente, 1999) describes the work domain affordances using an Abstraction Decomposition Space (ADS), often referred to as an Abstraction Hierarchy. ADS is a structural means-ends and part-whole decomposition of the work domain. The decomposition feeds directly into a design where the structure's components are represented in the interface so that problems can be readily detected and diagnosed. Well-defined and deterministic work domains are readily described with an ADS.

CWA also includes the decision ladder modeling tool which is a template for information processing. The ladder interacts with the ADS as information flows in a loop between these two frameworks. In this respect, both TTA and CWA analyses address human activity within an environment although their emphasis differs.

A new method for describing the work domain is based on Personal Construct Psychology (PCP). Kelly (1955) introduced PCP to explain how people conceptualize their world. It is based on the axiom that humans are essentially scientists who actively generate and test their hypothesis by construing a personal system of constructs. A network of constructs is continually being formed and revised in order to maintain or strengthen the predictive power of the hypothesis in relation to reality. These conceptual structures could be elicited from SMEs and be compiled into a work domain description.

The Repertory Grid (RG) is an effective elicitation technique (Sewell et al., 1992). RG allows the analyst to determine the operator's own finite number of dichotomous personal constructs for a given do-

P515430.PDF [Page: 4 of 6]

102-01726/

main. It also prompts the SME to think about relevant dimensions of the work domain. Combined with a principal components analysis, PCP may yield a robust work domain model from the operator's perspective.

The fourth analysis technique is based on Perceptual Control Theory (PCT). Powers introduced PCT as an alternative framework for human cognition (Powers, et al., 1960). Its core tenet is that all behavior results from the control of perception. This implies that goals are internal to the human rather than external as with traditional human-machine interaction models. The framework is a classical control feedback loop where sensory information, perceptions, perceptual goals and errors, behaviors and disturbances are the variables around the loop, and perception, comparison, decision-making, and environmental functions are the loop's transformations. In PCT, the work domain and human structures and variables are all part of this single model, and so it is expected that PCT would be a viable framework for both types of work domain descriptions.

The Perceptual control theory Analysis Technique (PAT) (Farrell and Chéry, 1998) yields a hierarchy of perceptions and behaviors and the related work domain structures. PAT accommodates both descriptive and mathematical expressions, and a computer program is currently being developed for dynamic simulation of the human-environment interaction at multiple levels of abstraction.

While TTA, CWA, PCP, and PCT include work domain structures and variables to more or lesser degrees, a unified method should provide an appropriately balanced description. This balance will depend on the domain itself. For example, an operator may rely on the plant's structure in order to diagnose a problem, while a doctor needs to detect environmental variables in order to diagnose a medical condition. In the military context, all possible tactics and the current tactical evolution (structure and variable knowledge) are necessary to make timely decisions towards mission completion. Thus, the method may need to focus on the domain structure rather than its variables, visa versa, or an equal balance of both.

In exploring the work domain analysis techniques, four descriptions were generated and compared for the same work domain. There are two major limitations on studies of this sort. First, it is difficult to find a single work domain that would bring out the fundamental characteristics of each method employed. Second, the work domain descriptions depend on who does the analysis and their level of expertise. A complete comparison that has statistical significance might involve five work domains, four related areas of expertise, and twenty experts from each area. Needless to say, the ensuing analysis would be formidable. Keeping these assumptions in mind, we still hope to discover the predominant features that provide clues into how the methods can be synthesized.

METHOD

Communication within the Griffon helicopter was chosen as the work domain because two of the four descriptions were available. Canadian Marconi Company (1999) developed a composite mission scenario related to helicopter communications. The scenario represents a TTA work domain description. It described opposing forces and their capabilities, helicopter roles, goals, strategies, timings, geographical locations, aircraft systems status, weather, and mission-related intelligence. What the scenario does not provide is specific references to aircraft or support systems equipment.

An abstraction hierarchy for communication within the Griffon was generated, and it was the basis for an Ecological Interface Design (EID) of a Control Display Unit (Chéry, 1999). This work was a departure from power plant applications, which is common for this technique. Table 1 is a summary of the ADS. The purpose is to permit voice communication among parties. The next level describes a general communication model that involves source entropy, encoder, channel, possible interference, decorder and destination entropy. The principles of radiophony are followed by a description of the equipment and physical form.

The method used for the PCP work domain analysis technique is described below. Five SMEs were asked to participate in an interview process where the RG software was used. The domain experts were a former Griffon pilot and instructor, a computer programmer and project manager, a systems design engineer, a psychology graduate student and experimental observer, and a human factors specialist familiar with all techniques. All participants were experts with respect to communication within the Griffon Helicopter since they were involved in a contract that required the implementation of direct voice input within the Griffon Helicopter for communication purposes.

The interviews lasted two hours. The SMEs were briefed on the goals of this paper, reviewed the work domain definition and scenario, had a Repertory Grid tutorial, performed the elicitation exercise, and participated in a debrief. A principal component analysis was performed during the debrief, and the results were compared across participants. The SMEs commented on whether the exercise brought new insight into their understanding of the work domain. The principal components from each interview were synthesized into a global set of components that represented the PCP work domain description.

P515430.PDF [Page: 5 of 6]

Table 1. Means-end levels for communication domain (Chéry, Vicente, and Farrell, 1999).

[illegible]	Permit voice communication between remotely located parties
[illegible]	Entropy at source, channel, equivocation, noise, encoder, decoder, entropy at destination
[illegible]	Signal transduction, frequency generation, interference generation, modulation, radiation, propagation, extraction, refraction, demodulation, absorption, attenuation, interference reduction, frequency conversion
[illegible]	Microphone, electric source, ionosphere, terrain, airspace, antenna, filter, modulator, demodulator, oscillator, correcting network, speaker
[illegible]	Location, appearance, and physical connections

RESULTS

The results from the RG and PAT work domain analysis techniques are briefly summarized as follows. Table 2 lists the global principal components derived from the PCP method. The components in bold were those found by two or more SMEs and the plain text components were unique. Each SME contributed at least one unique component. Note that the components describe what the work domain is (e.g., human and equipment states) and what it does (e.g., crew activities).

A full PAT analysis was generated, based on Chéry's initial work, that looked at the work domain variables and related transformations. Table 3 includes both human and environmental structures that are barriers to communication. The plain text descriptors are identical to those in Table 1, as was the intent, in order to see if the ADS descriptors could be fit into a PAT framework.

DISCUSSION

The work domain descriptions were compared across techniques. The TTA scenario provides a broad understanding of the work domain. Familiarization flights and video review were used to generate the scenario. Some of the work domain descriptors, like *aircraft system states, weather, radios, etc.*, are implicit in the scenario as there is no requirement within TTA to make the work domain explicit. However, one unique and important descriptor is *opposing forces*. One reason why other techniques did not capture this component is because the SME has higher implicit goals than just communication. The scenario narrative generally stayed within the communication work domain, but occasionally it moved outside that domain and into a larger work domain that involved the overall mission objectives.

Table 2. Global Principal Components from RG

[illegible]
transmission ability
Transmission type
human and equipment states
crew activities
communication recipient
communication intensity
Navigation
CDU communication
other communication
Low level aviation
Air Traffic Control

The ADS approach captures the physics-based structure for the inanimate objects within the work domain. Only a small fraction of descriptors, like terrain and atmospheric conditions, were also found using the TTA and PCP techniques. However, TTA or PCP do not guarantee that a scenario or a RG analysis would capture any of the work domain structure.

ADS does not capture any of the human structures within the work domain. However, within the CWA process, the decision ladder is used to capture some of the human structures and limitations. As an aside, studies are underway to see if an ADS can be used to describe social and organizational work domains (Rasmussen, 1999).

The PCP principal components describe the work domain at a relatively high level. Each SME

Table 3. PAT Work Domain Description

originator-encoder-channel-decoder-recipient stucture	*Navigate and aviate*, noise and equivocation
frequency conversion, signal transduction, frequency generation, *encryption* LPT and GPG structures	Interference generation, extraction, radiation, propagation, refraction, absorption, reduction, attenuation, *improper codes*
Input device-software algorithms- radios with scanning, KY units, power supply-software algorithms-display, *tactical model* *GPG model - Vocal model* – microphone-ideal medium – head phones – *Ear model - GPG model*	Airspace, ionosphere, terrain, radio wave barriers, agent position, equipment failures Interface incompatibility Other mental activities Physiological disturbances Accents, unexpected mental *models of originator*
Microphone (oscillator, modulator), speaker (demodulator)	*Interfering pressure waves, electrical disturbances, magnetic disturbances*
kinematics and dynamics of finger-key interaction	*Undetected internal structural defects of the finger*

P515430.PDF [Page: 6 of 6]

515430

CA010623

either described the work domain in terms of what it is or what it does, depending on their own preferences. The results show that the work domains of aviation, navigation, and communication overlap, as these are the principal tasks of the helicopter crew. These results could be used to define the work domain at the highest levels.

The *Air Traffic Control* descriptor is unique because the technique has the ability to bring together information from many sources. However, the number of SMEs needed to ensure a comprehensive work domain description is unknown.

Environmental structures as well as human limitations are identified by PAT. Unlike ADS, the environmental structure is parsed into models that promote communication (i.e., transformations) and those that disrupt communication (i.e., disturbances). Anticipated disturbances can be monitored and compensated for, and unanticipated disturbances (originating from outside the given work domain) can be detected as a perceptual error.

There are some unique descriptors related to psychological and physiological structures that also provide the boundaries for behavior and perception such as *recipient's mental models of originator* and *kinematics and dynamics of finger-key interaction*.

Although, there is much overlap in the work domain descriptions, each technique yielded a unique set of descriptors. The techniques study the same work domain, but from several perspectives. The scenario provides a global perspective. The PCP analysis is powerful because it can synthesize many SME perspectives into a set of high level principal components. ADS is the most direct mapping of the work domain structure. PAT includes human limitations as well as the work domain's structure and variables in the work domain description.

In order to generate a comprehensive work domain description that captures the contributions of each technique, the analyst would need to perform all work domain techniques to some extent. But is there an efficient approach one might take?

One possible approach is to begin with a scenario, which is an efficient way to become familiar with the work domain with minimal resources. Next, a PCP analysis can provide high level constructs that effectively define the work domain purpose. The principal components can be used to generate a purpose level description for an ADS analysis. The ADS analysis may then divide the work domain into means-end and part-whole relationships. The PAT analysis can be used to verify the ADS structure as well as generate internal and external psychological and physiological structures that also constrain human activity.

A work domain analysis must be performed with care since the rest of the Human Factors analysis and design process is based on the description itself. A synthesis of work domain techniques promises to provide a comprehensive work domain description towards effective system design.

REFERENCES

Canadian Marconi Company. (1999). DVI Composite Mission Scenario. Prepared under contract (noW8477--AC40/001/SV) for the Defence and Civil Institute of Environmental Medicine, Toronto, Canada.

Chéry, S. (1999). Applying Ecological Interface Design and Perceptual Control Theory to the Design of the Control Display Unit. Unpublished master's thesis, Graduate Department of Mechanical & Industrial Engineering, University of Toronto. Toronto, Canada.

Chéry, S., K. J. Vicente, and P. S. E. Farrell (1999). Perceptual Control Theory and Ecological Interface Design: Lessons Learned from the Control Display Unit. In proceedings of the *43nd meeting of the Human Factors and Ergonomics Society*, Houston, Texas, September 1999.

Farrell, P. S. E. and S. Chéry (1998). PTA: Perceptual Control Theory Based Task Analysis. In proceedings of the *42nd meeting of the Human Factors and Ergonomics Society*, Chicago, Illinois, October 1998: 1314-1318.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Company

Kelly, G.A. (1955). *The Psychology of Personal Constructs*. New York, Norton.

Miller C A., and K J. Vicente (1998). Toward an Integration of Task- and Work Domain Analysis Techniques for Human-Computer Interface Design. In proceedings of the *42nd meeting of the Human Factors and Ergonomics Society*, Chicago, Illinois, October 1998: 336-340.

Powers, W.T. Clark, R. K., and McFarland, R. L. (1960). A general feedback theory of human behavior: Part 1, *Perceptual and Motor* Skills, 1960, 11, 71-88.

Rasmussen, J. (1999). Systems Research Problems in a Dynamic Society. A presentation sponsored by HFIG, Department of Mechanical and Industrial Engineering, University of Toronto. Toronto, Canada.

Sewell, K. W., J. Mitterer, J. Adams-Webber, R. L. Cromwell (1992). Computerized Repertory Grids: Review of the Literature. *International Journal of Personal Construct Psychology*, 1992, Vol. 5, No1, 1-23.

Van der Veer, R. and J. Valsiner (1994). *The Vygotsky reader*. Blackwell Publisher.

Vicente K. J. (1999). *Cognitive Work Analysis Toward Safe, Productive, and Healthy Computer-Based Work*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Weiten, W. (1989). *Psychology Themes and Variations* Pacific Grove, California: Rooks/Cole Publishing Company.

© British Crown copyright 2000. Published with the permission of the Government of Canada and the Canada Department of National Defence.